PROTECTING KNOWLEDGE:

HOW LEGAL REQUIREMENTS TO REVEAL INFORMATION AFFECT THE IMPORTANCE OF SECRECY

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Abstract

Most firms use secrecy to protect their knowledge from potential imitators. However, the theoretical foundations for secrecy have not been well explored. We extend knowledge protection literature and propose theoretical mechanisms explaining how information visibility influences the importance of secrecy as a knowledge protection instrument. Building on mechanisms from information economics and signaling theory, we postulate that secrecy is more important for protecting knowledge for firms that have legal requirements to reveal information to shareholders. Furthermore, we argue that this effect is contingent on the location in a technological cluster, on a firm's investment in fixed assets and on a firm's past innovation performance. We test our hypotheses using a representative sample of 683 firms in Germany between 2005 and 2013. Our results support the moderation effect of a technological cluster and a firm's investment in fixed assets. Our results inform both academics and managers on how firms balance information disclosure requirements with the use of secrecy as a knowledge protection instrument.

Keywords: Secrecy; Information disclosure; Knowledge visibility; Technological clusters; Innovation performance

1. Introduction

The threat of imitation by competitors of a firm's unique knowledge is central to theories on knowledge-based competitive advantages of innovative firms (Spender and Grant, 1996). Many firms counter this threat by keeping their R&D activities secret. Then again, legal requirements and accounting standards require firms to disclose information regularly to shareholders, and this information is also potentially available to competitors. The goal of this study is to explore how these requirements change the importance of secrecy for protecting knowledge in innovation activities. Considerations for mandatory information disclosure are largely absent in existing literature, predicting that secrecy is most important for firms lacking resources and technological or legal opportunities to apply for patent protection (Bos, Broekhuizen and de Faria, 2015 provide a recent review). We draw on information economics and signaling theory and argue that the importance of secrecy is influenced by the visibility of a firm's activities to potential imitators. The more visible a firm, the more vulnerable it is for imitation.

Secrecy is a widely used and efficient knowledge protection mechanism in virtually all industries and firms of all types and sizes (Bos et al., 2015; Hall, Helmers, Rogers and Sena, 2014; Harabi, 1995; James, Leiblein and Lu, 2013). Firms actively restrict information flows both within and outside their boundaries with the objective of limiting unintended information spillovers (James et al., 2013). Research has emerged that stresses secrecy as an important factor in "make or buy" decisions (Cassiman and Veugelers, 2006), its relation with other protection mechanisms such as lead-time or patenting (Arundel, 2001; Cohen and Walsh, 2000) and its effect on strategic alliance decisions (Katila, Rosenberger and Eisenhardt, 2008). However, despite the wide use of secrecy as a knowledge protection instrument in managerial practice, we know little about the importance of secrecy for firms that are increasingly visible to potential imitators.

The essence of secrecy is the creation or extension of an information asymmetry between a firm and potential imitators with regard to the firm's knowledge stock. We argue that the importance of

secrecy as a knowledge protection instrument depends on how visible a firm is to its competitors. Since the quality of a firm's knowledge is often difficult for external parties to directly observe, potential imitators rely on observable quality signals to select their imitation targets (Stuart, Hoang and Hybels, 1999). The major sources of information for competitors are firms' own financial reports, where firms disclose information based on legal regulations of a specific country (Fishman and Hagerty, 2003). We argue that firms that are legally required to share information with their shareholders will be more visible to potential imitators. Consequently, secrecy will become more important as a knowledge protection instrument because visible firms will find it more important to create an information asymmetry by using secrecy to protect their knowledge from imitation. Furthermore, we hypothesize that this effect of legal mandatory information disclosure requirements on the importance of secrecy is moderated by the location of a firm withina technological cluster, the level of investment in fixed assets and its past innovation performance. All these factors increase the firm's visibility to potential partners and, when combined with mandatory information disclosure, lead to a stronger increase in the importance of secrecy.

We test the hypotheses using a representative sample of 683 firms in Germany between 2005 and 2013. We show that secrecy is more relevant for protecting knowledge for firms that have legal requirements to reveal information to shareholders. Moreover, we find support for the moderation effect of technological clusters and firms' investment in fixed assets. Our findings have important implications for two primary streams of research. First, we add to the literature on knowledge protection by showing specific contingency factors for when secrecy is especially important. Existing literature on knowledge protection and appropriability has described the importance of secrecy as depending on knowledge characteristics, industry factors and cost considerations (James et al., 2013; Bos et al., 2015). We go beyond these findings, and provide a theoretical model that links the importance of secrecy to the visibility of the firm. Second, we contribute to a stream of research that has compared the effects of various knowledge protection instruments and their interactions but that treats them as exogenous (Hussinger, 2006; Jensen and Webster, 2009). Our findings show that this assumption is too strong and

that the importance of secrecy can be traced back to how visible the firm is. More comprehensive models will be able to eradicate a potential source of bias by taking these endogenous relationships into account when estimating performance effects. These academic implications have consequences for managerial decision-making. Our findings show that firms need to adjust their knowledge protection if they are more visible to potential imitators. Firms with mandatory requirements to disclose knowledge located in technological clusters and that make higher investments in fixed assets will need to prepare for potential imitators which may previously have overlooked the firm. Under such conditions, secrecy becomes more important for knowledge protection, and firms should reassess access to sensitive laboratories, databases or R&D personnel.

The remainder of the analysis is structured as follows. The next section reviews core theoretical constructs and mechanisms associated with secrecy as a knowledge protection instrument. In the hypotheses development section, we elaborate on our predictions regarding the relationship between firm visibility and the importance of secrecy. The subsequent section describes the empirical study, followed by the results. We conclude by discussing the results, deriving conclusions and identifying directions for further research.

2. Theoretical framework

Our theoretical model is directed at explaining heterogeneity across firms regarding the importance they attribute to secrecy as a knowledge protection mechanism. While all firms have strong incentives to protect their knowledge from competitors, some find secrecy more useful than others, thus reflecting the importance of secrecy for knowledge protection (Conti, 2014). We begin by defining key constructs that establish the theoretical mechanisms of knowledge protection by secrecy and that differentiate secrecy from other forms of knowledge protection. This provides us with a basis for extending the framework in the hypotheses section.

Firms can increase their innovation performance if they create innovations that allow them to set higher prices based on an at least temporary monopoly position in the product market, or benefit from comparatively lower costs due to process innovations. In both cases, the competitive advantage disappears once competitors acquire the underlying knowledge of the innovation and imitate products or processes (Arrow, 1962). Consequently, sustainable competitive advantage can only be achieved if competitors can be prevented from using a firm's knowledge (Liebeskind, 1996).

All forms of knowledge protection are centered on the idea of making the imitation of a firm's knowledge as costly and risky as possible (for a review on imitation, see Ordanini, Rubera and DeFillippi, 2008). In fact, there is considerable evidence that imitation is oftentimes incomplete (Westphal, Seidel and Stewart, 2001) or error-prone (Denrell, 2003). Errors in imitation are consequential because of the substantial related costs. Indeed, estimates of imitation costs range between 25 percent (Shenkar, 2010) and 65 percent of the original innovation expenditures and can take 70 percent of the time to develop (Mansfield, Schwartz and Wagner, 1981). Among firms' active strategies to protect their knowledge, patenting and secrecy are the dominant forms. While the former has received ample attention in management research (e.g., Levitas and McFadyen, 2009; McGahan and Silverman, 2006), the latter has been much less explored theoretically. This oversight is surprising because secrecy has been found to be among the most important forms of knowledge protection for firms of all sizes and industries (Arundel, 2001; Harabi, 1995). Our focus is therefore on secrecy.

Patents require the disclosure of the knowledge associated with the innovation and prevent imitation through the threat of punishment in court. The mechanisms underlying secrecy are fundamentally different because they try to prevent or at least delay the imitation process by non-disclosing the underlying knowledge. We define secrecy as all restrictions at the firm level that prevent unintended knowledge flows outside of firm boundaries. The essence of secrecy is, therefore, to make the imitation search process as costly and unpredictable as possible by preventing any information outflows concerning internal knowledge. By making knowledge invisible to outsiders, secrecy makes it difficult for

imitators to identify a firm as a promising source for imitation and to access its knowledge once it has been identified. The widely used example for the latter is the original Coca-Cola recipe, which has never been legally protected, but which has been kept secret (Hannah, 2005). Often, the implementation of secrecy also has a legal component (Png, 2017; Castellaneta, Conti, Veloso and Kemeny, 2016). However, in contrast to the legal protection by patents that aim at preventing the use of protected knowledge but not its diffusion, legal trade secrets have the objective of reducing the risk of misappropriation and imitation by limiting information flows (Castellaneta, Conti and Kacperczyk, 2017).

While knowledge per se has some characteristics of public goods, firms can limit access to where it is physically produced and stored, who can access it and whether the authorized personnel can transfer it. Secrecy measures are therefore sets of rules that limit the transfer of knowledge to specified others, social interactions with them or restrictions on physical access to certain locations, e.g., laboratories (Liebeskind, 1996). Employees may be granted access to knowledge only after they have made a contractual commitment to knowledge protection, e.g., non-competition clauses for discontinuations of labor contracts (Katila et al., 2008). Secrecy is frequently used because of its flexibility compared with patenting. It can be applied to all types of knowledge (e.g., non-codified, tacit, early stage) and achieved through internal procedures instead of legal procedures, and it does not expire (Encaoua, Guellec and Martinez, 2006; Hannah, 2005; Maurer and Zugelder, 2000). In contrast, only 32 percent of all inventions are ever patented and patent propensity varies significantly across industries, e.g., 74 percent of all innovations are patented in pharmaceuticals (Arundel and Kabla, 1998).

Despite its broad applicability, the effectiveness of secrecy depends on the nature of the knowledge that the firm wants to protect (Bos et al., 2015). Secrecy is particularly effective for protecting knowledge that by its nature is easier to keep invisible from potential imitators. Consequently, secrecy is especially effective for protecting innovations based on complex or tacit knowledge that is difficult to codify and replicate (Amara, Landry and Traoré, 2008), such as process innovations that tend to be hidden within the firm (Gonzalez-Alvarez and Nieto-Antolin, 2007), and products with relatively short

life cycles (Blind and Thumm, 2004). The effectiveness of secrecy also depends on the innovation development phase since it is easier to keep knowledge hidden from potential imitators when an innovation is in the premarket development phase (Arundel, 2001; Cohen, Nelson and Walsh, 2000).

We build upon these existing findings and delineate the theoretical mechanisms of what makes secrecy especially important as a knowledge protection instrument based on information economics and signaling theory arguments. The essence of secrecy is the creation or extension of an information asymmetry between a firm and potential imitators with regard to the firm's knowledge stock. The value of this knowledge stock represents the economic value of future returns from a firm's investments in knowledge production through R&D. Firms differ regarding how visible their activities are to potential imitators. When information about the value of the knowledge stock of a particular firm is limited, potential imitators have difficulties distinguishing between valuable inventions to imitate and worthless inventions to ignore. In the following, we will theorize on how firm visibility influences the importance attributed by firms to secrecy as a knowledge protection instrument.

3. Hypotheses development

The primary assumption for our hypotheses is that potential imitators operate under conditions of information asymmetry. Consequently, firms are often unable to make fully informed decisions (Stiglitz, 2002). Many decisions imply the assessment of the capabilities and potential of other firms, and this information is often difficult to get (Chaddad and Reuer, 2009). Firm insiders have information about firms' capabilities while outsiders, e.g., investors, customers and competitors, only have partial information about the firm (Kirmani and Rao, 2000). Consequently, in order to make a more informed evaluation, external parties look for signals that offer indications on the unobserved ability of a firm (Connelly, Certo, Ireland and Reutzel, 2011).

Such signals are also relevant for potential imitators. In fact, imitation can be understood as a general search process under conditions of uncertainty (Haunschild and Miner, 1997). Ex ante, the

imitating firm cannot know which competing firm, or which part of the competing firm's knowledge, is worth imitating. Similar to traditional search theory, the imitating firm would like to consider all potential competitor knowledge, but resources, as well as management attention for searching and screening, are limited (Koput, 1997). The imitator, thus, finds itself in a tradeoff between searching too broadly or too narrowly. In order to decrease the search and imitation costs, imitators will target their attention toward firms whose activities are more visible and consequently easier to evaluate. Important and easily available information sources are firms' own financial reports, where firms disclose their financial situation, earnings and costs in order to inform their shareholders or the public. We argue that secrecy is a more important knowledge protection instrument for firms that are legally obliged to disclose information, because the availability of the disclosed information makes them more visible to potential imitators.

Financial reporting and disclosure are important means for communicating firm performance to stakeholders and outside investors (Healey and Palepu, 2001). Firms provide disclosure through financial reports, or voluntary communication, such as analysts' forecasts, press releases or corporate reports. Existing research shows that disclosures are relevant for firms because companies can benefit by reducing the costs of capital (Clarke, 1983) or improving liquidity (Diamnond and Varrecchia, 1991). Companies differ in the demands for accounting and disclosure (Burgstahler et al., 2006). Specifically, public firms, which are financed by external stakeholders, face higher demands for disclosure because investors do not have private access to company information and rely on public information, such as financial statements to make decisions. The quality of the disclosed information determines investors' willingness and reluctance to invest capital in these firms so that public companies have higher incentives to provide information that helps external stakeholders evaluate firms' decisions and the resulting performance. Due to the standardization of accounting requirements, private limited companies are, however, also facing requirements to disclose their information publicly. In the European Union, for example, accounting and disclosure standards are determined by the legal form of the company so that private and public limited firms face the same mandatory disclosure requirements (Burgstahl et al., 2006).

The legal requirements to reveal information to shareholders also make general information about the firm available to competitors. An important part is financial information, such as equity investments, bank loans, asset investments, sales revenues or profitability. Previous research has shown that this financial reporting is most likely to contain information that signals the innovation potential to external parties (Cohen et al. 2012). Therefore, disclosures can be consequential because they can reveal relevant information to potential imitators (Verrecchia, 1983; Healy and Palepu, 2001). Disclosure decisions, thus, involve a tradeoff between reducing investor uncertainty regarding a company's performance on the one hand, and revealing important information to competitors on the other (Dedman and Lennox 2009; Li 2010). Competitors can use disclosed information to their advantage, thus impairing the future performance of a disclosing firm. We argue that firms that are legally required to reveal information will more actively try to create information asymmetry with potential imitators regarding knowledge that is not reported in mandatory statements. In particular, we expect that these firms will try to keep information about their innovation activities, such as the development of new prototypes or of new manufacturing processes, hidden from potential imitators. Consequently, for these firms that are legally required to reveal information, secrecy will be more important as a knowledge protection instrument. We hypothesize:

> Hypothesis 1: Secrecy is more important as a knowledge protection instrument for firms that are legally required to disclose information to external parties than for firms that do not have this legal requirement.

While firms that are obligated to disclose information report their overall value periodically to shareholders, regulators, tax authorities or the general public per se, the valuation of its knowledge stock is not necessarily identical to the outside expectations about its value (Chaddad and Reuer, 2009; Levitas and McFadyen, 2009; Ndofor and Levitas, 2004). We expect the effect of visibility associated with information disclosure to vary with specific firm characteristics. Specifically, we predict that the effect of mandatory disclosure of information on the importance of secrecy will be stronger for firms located in

technological clusters, with higher levels of fixed asset investment and that had a higher product innovation performance in the past. In the following hypotheses we will discuss how the main mechanism described in hypothesis 1 is influenced by these factors.

We start out by discussing the role of technological clusters. A technological cluster is a regional concentration of technological activity in an industry (Alcácer and Zhao, 2012). Firms situated in these clusters have access to a pool of knowledge that is generated by a dense network of firms and universities (Saxenian, 1996). This common pool of knowledge is created due to three main mechanisms. First, due to the fact that knowledge flows are particularly likely to occur between firms that are located in the same region (Almeida and Kogut, 1999; Jaffe, Trajtenberg and Henderson, 1993) and that this direct interaction between firms stimulates the creation of common knowledge between them (Powell, Koput and Smith-Doerr, 1996). Second, firms that are located in the same region often rely on common buyers and suppliers. This creates an indirect interaction with competitors and, therefore, facilitates the creation of a shared pool of tacit and valuable knowledge (Alcácer and Chung, 2007). Finally, the high concentration of firms also increases job mobility because individuals tend to move to nearby, existing firms (Almeida and Kogut, 1999) or new ventures (Glaeser and Kerr, 2009). Consequently, firms located in clusters are more involved in knowledge flows because employees who change jobs act as knowledge transfer agents (Rosenkopf and Almeida, 2003). Taken together, these mechanisms suggest a direct positive effect from location in a technological cluster on the importance attributed by firms to secrecy as a way to protect their knowledge. We reason that the general effect from location in a technological cluster will reinforce the positive effects of legally required information disclosure for a focal firm on the importance of secrecy.

Technological clusters create a context in which the risks of imitation are comparatively higher for all firms since potential imitators within clusters are better prepared to read and interpret quality signals (Brown and Duguid, 2001) and have higher levels of mutual absorptive capacity (Tallman, Jenkins, Henry and Pinch, 2004). However, potential imitators would still need to identify particular firms, which are the most promising targets for imitation within a technological cluster. Especially technologically vibrant

clusters such as Silicon Valley have large numbers of startups and laboratories experimenting with broad varieties of technologies and functionalities. Given the substantial costs and risks of imitation (Lieberman and Asaba, 2006; Ordanini et al., 2008), imitators cannot choose imitation targets randomly. Financial information such as equity investments, bank loans, asset investments, sales revenues or profitability of innovative firms can provide signals for their innovation potential as well as for its value for potential imitators. Firms without legal requirements for information disclosure can keep such financial information private. Firms with legal requirements to reveal information, though, face higher risks of imitation since their activities are more visible and consequently easier to evaluate by potential imitators. Given that their information disclosure is legally mandated and that omissions or misinformation can have substantial legal consequences, the disclosed information provides particularly reliable information to potential imitators. We reason that this signaling effect is comparatively more consequential within a technological cluster since potential imitators are particularly apt in interpreting the signals within a cluster. They develop similar knowledge (Powell et al., 1996), can turn to shared buyers or suppliers for information (Alcácer and Chung, 2007) or hire key personnel from innovative firms (Almeida and Kogut, 1999).

Consequently, we expect that firms located in a technological cluster, when compared with their counterparts located elsewhere, will face higher risks of imitation and will attribute comparatively more importance to secrecy as an instrument to keep knowledge that is not revealed in mandatory disclosure agreements invisible to potential imitators. We propose:

> Hypothesis 2: Secrecy is more important as a knowledge protection instrument for firms that are legally required to disclose information to external parties than for firms that do not have this legal requirement, and this difference is larger for firms located in a technological cluster.

We discuss investments into fixed assets as a second moderating factor. Complementary asset theory links asset investments to the value that firms can capture from innovation (Teece, 1986). Complementary assets can be non-fixed (e.g., customer base) or fixed in nature (e.g., manufacturing plants, distribution and service networks or sales organizations). We focus on the latter because of their

higher visibility. While complementary assets are crucial for capturing value from a technological invention, they require financial investments. Resource-constrained firms have been found to even forgo the commercialization of technologies because of the investments in complementary assets that they would have required (Arora et al., 2001).

The direction of the main effect of investments in fixed assets on the importance of secrecy for a focal firm is not obvious. On the one hand, such investments can send visible signals to potential imitators that a firm wants to commercialize a sizable innovation worth imitating. On the other hand, firms controlling significant complementary assets such as production facilities could increasingly rely on these assets for capturing value from their innovations instead of secrecy. The exploration of this direct effect is not central to our study. Instead, we are concerned with how investments into fixed assets moderate the effect of legally required information disclosure on the importance of secrecy for knowledge protection.

Investments in fixed assets are not necessarily sending signals to potential imitators of a focal firm's innovation activities. These investments can be potentially unrelated to innovation or exploiting old technologies, e.g., storage facilities. Hence, it is important that imitators can infer specialized complementarity (Teece, 2006) between a firm's fixed asset investments and its innovations. Imitators would find it difficult or even impossible to make these assessments systematically for innovative firms that do not disclose information to the public. However, firms that are legally required to disclose information are much more likely to explain the purpose of their fixed asset investments to particular investors or banks, credit rating agencies or analysts in general. Investments into manufacturing plants or sales offices are likely to be justified by the anticipated demand for innovative products or services (Eckhardt and Shane, 2003). This information is also available to potential imitators and increases the risk of imitation. Tesla provides a fitting example for the way in which its prospectus filed with the U.S. Securities and Exchange Commission (SEC) in 2010 describes how proceeds will be used for fixed asset investments as well as the relationship with its innovative products (excerpt):

> *"We currently anticipate making aggregate capital expenditures of between $100 million and $125 million during the year ended December 31, 2010. These capital expenditures will include approximately $42 million to purchase our planned Tesla manufacturing facility for the Model S in Fremont, California, excluding any manufacturing equipment we may subsequently acquire. Our aggregate capital expenditures will also include funding the expansion of our Tesla stores. We expect to use a portion of the net proceeds to fund this expansion, which we estimate will cost approximately $5 million during the year ended December 31, 2010 and an additional $5 million to $10 million annually over the next several years thereafter to establish approximately 50 stores globally."*

In sum, legal requirements for releasing information combined with investments into fixed assets by an innovative firm send particularly visible signals to potential imitators. Given these signals, the incentives for innovative firms to keep the knowledge underlying their innovations secret increase, and we consequently expect that these firms attribute more importance to secrecy. We hypothesize:

> Hypothesis 3: Secrecy is more important as a knowledge protection instrument for firms that are legally required to disclose information to external parties than for firms that do not have this legal requirement, and this difference increases with a firm's investment in fixed assets.

The uncertainty about a firm's R&D investments has two main components (Amit, Glosten and Muller, 1990). The first one is related to the potential of R&D investments to lead to technologically feasible inventions. This technological uncertainty originates from the fact that experiments may fail completely or produce outcomes that do not meet expectations and requirements. For example, pharmaceutical research relies heavily on combining chemical compounds for producing new drugs through experimentation. A vast majority of these experiments do not lead to a successful drug or produce a drug without the desired medical effect (Thomke and Kuemmerle, 2002). The second uncertainty component is related to the commercial success of inventions. Even if R&D activities lead to the creation of a technologically feasible invention, economic success could be disappointing since the invention may not meet customer demands or may have lower quality than competing products. Gourville (2006) estimates that, depending on the product category, 40 to 90 percent of all innovations fail after they have been introduced into the market. Hence, there is a substantial market uncertainty component.

Based on the premise that the best predictor of future performance is past performance, we argue that past product innovation success provides a strong signal for the true value of a firm's knowledge stock. Innovation success in terms of realized sales not only implies that the invention is novel and technologically feasible but that it also has economic value, as evidenced by the customer's willingness to pay for it. In essence, a track record of successful products gives an indication that both technology and market uncertainty inherent in performance firms' R&D projects are reduced. What is more, potential imitators are very likely to operate in similar markets and technology environments (Dussauge, Garrette and Mitchell, 2000). Successful innovations in these markets can be expected to be directly relevant and observable to them. We argue that successful firms draw the attention of imitators to their knowledge stock and face more risks of imitation. Consequently, we expect a direct positive relationship between past innovation performance and the importance attributed by firms to secrecy as a knowledge protection mechanism.

In addition to this direct effect, we also anticipate that past innovation success moderates the effect of legally required information disclosure on the importance of secrecy for knowledge protection. We claim that past innovation performance provides a signal that complements the information revealed by firms in their reporting. Financial reporting contains information that signals the innovation potential of a firm to external parties (Cohen et al., 2012), and past innovation success strengthens this signal by indicating that a firm is able to develop innovation activities that lead to economic returns. We expect that firms that provide detailed information about their activities and have a record of success conducting innovation activities will be targeted by imitators as valuable sources of knowledge and consequently will attribute more importance to secrecy as a knowledge protection mechanism. That is, we argue that the general effect from previous success in innovation activities will increase the positive effect of legal requirements to disclose information on the importance of secrecy. We hypothesize:

Hypothesis 4: Secrecy is more important as a knowledge protection instrument for firms that are legally required to disclose information to external parties than for firms that do not have this legal requirement, and this difference increases with a firm's past innovation performance.

4. Empirical study

4.1. Data and sample

We use data from the German Innovation Survey "Mannheim Innovation Panel" of 2005, 2011 and 2013. The survey is the German contribution to the European Union's Community Innovation Survey (CIS). The CIS survey is directed at decision makers on innovation activities within companies from different manufacturing and service sectors, such as CEOs, the heads of R&D or innovation management departments. The survey sample is stratified by region (East and West Germany), firm size and industry and, therefore, is representative for Germany as a whole. Decision makers on R&D or innovation management are asked directly if and how their firms are able to generate innovative products, services and/or processes. All core constructs on innovation inputs and outputs follow the OECD standard that is outlined in the Oslo manual (OECD, 2005). Moreover, CIS surveys are subject to extensive pre-testing and piloting in various countries, industries and firms with regard to interpretability, reliability and validity (Laursen and Salter, 2006). This multinational application of CIS surveys adds extra layers of quality management. It is therefore not surprising that CIS data have been the basis for several publications in highly ranked management journals (e.g., Laursen and Salter, 2006 for the UK; Leiponen and Helfat, 2010, 2011 for Finland).

Survey approaches are well-established in tracing innovation decisions at the firm level (e.g., Laursen and Salter, 2006; Leiponen and Helfat, 2010, 2011). We merge the survey data with patent statistics from the European Patent Office (EPO) and scientific personnel at the regional level collected by the Institute of Employment Research (IAB) of the Federal Employment Agency of Germany. We obtain data for competitive intensity (concentration) at the industry level from the leading German rating

agency, Creditreform, which is the basis for the Amadeus database of Bureau van Dijk and a frequently used database for the population of German firms. Industries are measured using the classification of economic activities in the European Community (NACE), while the regions are measured using a functional classification of the official regional German statistics ("Raumordnungregionen"). Such regions typically consist of an urban center and the districts that surround it. These agglomeration areas are not strictly based on administrative borders but rather reflect functional linkages such as commuter streams. The final sample is fairly representative of Germany, covering 46 industries at the two-digit NACE level and 95 geographical, agglomeration areas (Germany has 97 in total).

Our dataset originates from 683 firms, which have responded to the survey waves of 2005, 2011 or 2013. These survey waves ask respondents to assess the importance of secrecy for knowledge protection in their company in the preceding three years. Please see details on the time structure of the dataset in the next section. Most firms respond only once to the survey, resulting in a total of 812 firm observations for all estimations.[1] This specific structure of our data does not allow a difference-in-difference or fixed-effect estimation, but we are able to account for unobserved firm-specific heterogeneity by means of a random intercept.

4.2 Variables

4.2.1 Dependent variables

Our dependent variable measures the relative relevance of secrecy as a knowledge protection instrument compared to other knowledge protection instruments. The CIS questionnaire contains questions in which respondents assess the effectiveness of different knowledge protection instruments for their innovation activities on four-point scales, ranging from 0 = "not important at all" to 3 = "very important." The knowledge protection instruments comprise secrecy, patents, licenses, complexity of product design, lead

[1] 567 firms respond once, 103 respond twice (of which 76 in consecutive periods) and 13 firms respond three times.

time advantages and copyrights. We interviewed a number of managers from various industries about secrecy measures for innovation in their firms in order to infer whether their interpretations of secrecy are aligned with the theoretical construct. Most interviewees described organization-wide confidentiality trainings and agreements, which are combined with targeted measures limiting access to databases, prototypes or code. Appendix A provides a representative overview with illustrative quotes from these interviews.

Following Arundel (2001), we derive a measure of the relative importance of secrecy versus the other instruments at the firm level by creating the difference between the importance of secrecy and the average importance of all other instruments.[2] By this, we try to avoid inter-rater differences in the interpretation of the importance scales. We also use a different operationalization to test the robustness of our effects, where the dependent variable shows the rank of secrecy among all other knowledge protection instruments described above, and estimate ordered probit models which are described in the robustness check section 5.2.

The importance of secrecy and all other knowledge protection instruments is part of the CIS survey in 2005, 2011 and 2013. Our data consist of observations from all three years. In the survey, managers are asked to assess the importance for the three years previous to the survey, i.e., in the survey wave of 2013, secrecy is measured for the years 2012, 2011 and 2010. Accordingly, we use the independent variables from 2009 for the wave of 2013, from 2007 for the wave of 2011 and 2001 for the wave of 2005 to reduce reverse causality concerns[3].

[2] Arundel (2001) uses a relative measure of the importance of secrecy to patents. The strong focus on patents as a reference knowledge protection instrument appears too narrow for our research question and empirical setting.
[3] Our independent variables are lagged by one period with respect to the last period covered by the dependent variable, i.e., in the case of the survey wave 2013, the independent variables are from year 2009. Consequently, our independent variables contain the information from the years 2001, 2007 and 2009. We use year 2001 as a baseline.

4.2.2 Independent variables

To test the hypotheses, we need a variable that differentiates firms according to their legal requirement to disclose information publicly to shareholders. In the European Union, the legal requirements for information disclosure are determined by the legal form of the company (Burgstahler et al., 2006). The German Commercial Code ("Handelsgesetzbuch, HGB") requires firms to publish at least an annual report when they are a corporate, legal entity that applies to companies with limited liability and stock companies. Annual reports are the primary source of information and easily available to competitors (Beretta and Bozzolan, 2004; Elshandidy, Fraser and Hussainey, 2015). Consequently, we derive the variable "legal requirements to disclose information" that is valued 1 in case a company's legal form requires information disclosure. The reference group includes companies that do not have a separate legal entity from their owners, i.e., they are private companies or incorporated commercial partnerships. The operationalization by a dummy indicating the presence of mandatory information disclosure or not, is in line with previous studies that operationalize company reporting behavior (e.g., Garcia-Sanchez and Noguera-Gamez, 2017; Frias-Aceituno, Rodriguez-Ariza and Garcia-Sanchez, 2014).

We also need information on whether a firm is located in a technological cluster region, on a firm's fixed asset investments and on its past product innovation performance. Technological clusters are not easily captured because administrative headquarters do not necessarily identify the location of knowledge production (Alcácer and Zhao, 2012). We trace the geographical concentration of knowledge production in an industry based on employment statistics. For this, we use official employment statistics collected by the Institute of Employment Research (IBA) of the Federal Employment Agency of Germany. The data include a 50 percent, stratified sample of all employees in Germany and therefore serve as an excellent predictor for the regional distribution of skilled labor (Sofka, Shehu and de Faria, 2014). More precisely, the data provide information on the concentration of skilled employees (the share of engineers and scientists) as measures for technological clusters in a country at a combined industry and

regional level. The data are aggregated regionally at the level of agglomeration areas and two-digit NACE classification industry levels.

We use the share of scientists and engineers in the focal firm's region and industry relative to the total number of engineers and scientists working within this industry in Germany. We use this index as a determinant of whether this specific region is considered to be a technological cluster for the operating industry of a specific firm. This approach does not require the ex-ante definition of technological clusters, but provides a continuous measure on how near a specific region is to being a technological cluster for a specific industry.

We measure the level of investment of a firm on fixed assets in thousands of euro and logarithmically transformed. Lastly and in line with previous studies (e.g., Laursen and Salter, 2006; Nerkar and Roberts, 2004), we measure past product innovation performance with the firm's sales associated with new products. We normalize this variable by dividing it by a firm's total sales (Table 1).

4.2.3 Control variables

We control for several factors that may influence the importance of secrecy as a knowledge protection instrument for a firm. First, we add R&D intensity because R&D activities may affect the firm's need for knowledge protection by secrecy. We measure R&D intensity as a share of a firm's R&D expenditures to its total sales (Table 1). Second, we control for non-R&D innovation expenditures to take into account that some firms may be closer to commercializing their innovation than others. CIS surveys ask respondents to report innovation expenditures that not only include R&D, but also expenditures for the acquisition of equipment, licenses, software, market introduction, etc. We subtract firms' R&D expenditures from these total innovation expenditures and normalize the value by sales. Larger values indicate that firms are intensively investing in producing and/or selling their innovations.

We also control for the patent activities of firms by including the firm's stock of EPO patents. Specifically, we measure the patent stock with the natural logarithm of the number of patent applications. Weapply a depreciation yearly rate of 15 percent, which is a widely applied procedure in scientific publications (e.g., Aerts and Schmidt, 2008).[4] Furthermore, we control for the firms' degree of internationalization through the export share of sales, since the involvement in internationalization may trigger firms to more actively protect their knowledge (Golovko and Valentini, 2011).

Moreover, we control for structural differences among firms. We measure firm size by three dummies for small (less than 50 employees), medium (50 to 250 employees) and large firms (more than 250 employees). Large firms are used as a reference group. We control for whether a firm engages in process innovation because potential imitators can also aim at copying newly developed processes. We include company age (the natural logarithm of the number of years since founding) to control for potential "liability of newness" effects. A firm may also draw from the resources of a company group and benefit from knowledge spillovers, internal access to finance or other synergies. Hence, we include a binary variable for whether the firm is part of a group and differentiate between international and domestic MNCs because international and domestic groups differ with respect to their knowledge protection strategies and potentially with respect to the importance of secrecy (e.g., Sofka et al., 2014).

In addition, we control for effects due to competitive intensity within the focal firm's industry by adding the Hirschman-Herfindahl concentration index. Concentration indices are calculated using employment figures at a NACE two-digit industry level (indices using sales numbers are highly correlated). We also control for the personnel mobility within the industry and region of a firm. If a firm operates in an industry and is located in a region with high personnel mobility, secrecy may become more important, to avoid tacit knowledge outflows with employees who leave the firm.

[4] de Rassenfosse and Jaffe (2017) suggest that the R&D yearly depreciation rate varies in a range of 1 to 5 percent, a value considerably lower than our assumed value of 15 percent. As consistency checks, we estimated models where the patent stock has a depreciation rate of 3 percent and 5 percent. The results are fully consistent with our findings. The results are not presented in the paper but are available upon request.

Insert Table 1 about here

Knowledge protection depends on industry characteristics such as the appropriability regime and the nature of technological opportunities (Teece, 1986; Grimpe and Sofka, 2009). Cohen et al. (2000) related appropriability decisions to the complex or discrete nature of technologies in an industry. Following their industry classification, we introduce a dummy variable for manufacturing sectors with discrete technologies, e.g., in the production of food, textiles or metals. Additionally, we include industry dummy variables according to OECD classifications: medium high-tech manufacturing, high-tech manufacturing, distributive services, knowledge-intensive services and technological services. Low-tech manufacturing serves as a comparison group. We add two year dummies for years 2007 and 2009 with 2001 serving as a baseline to capture the remaining time-specific effects such as the overall growth of the economy.[5]

4.2.4 Descriptive statistics and correlations

Table 2 provides descriptive statistics for our data. On average, the positive relative importance of secrecy compared to other knowledge protection instruments indicates its relevance for the average firm in our sample. However, we see a high dispersion of the relative importance of secrecy, since the standard deviation is 1.03 higher than the mean value. 92 percent of the firms in our sample have legal requirements to disclose information. The average firm in our sample invests roughly € 4,600 (maximum € 1m) in fixed assets (in logs of thousands: 0.59) and has a share of past sales due to product innovations of 23 percent. Moreover, it spends 5 percent of its sales on R&D, slightly more than the average German average, and it is 17 years old. 6 percent of the firms are part of a foreign multinational group, and 11

[5] We also estimate a model with an industry classification based on the two-digit NACE codes. The results are in line with our main models presented in the paper and are available upon request.

percent are part of a domestic group. 42 percent of the firms in our sample are small-sized with less than 50 employees, and 37 percent are medium-sized with 50 to 250 employees. The major part of the firms in our sample operates in medium high-tech industries and technological services.

Insert Table 2 about here

An inspection of the correlation matrix (Table 3) does not reveal any multicollinearity issues, showing a mean variance inflation factor (VIF) of only 1.66 (maximal VIF value amounts 3.72). In addition, we test for common method bias by applying Harman's one-factor test and find no indication of common method bias: a principal component analysis for all of the model variables leads to 11 factors with an eigenvalue greater than one, and no factor explains more than 13 percent of the variance (Podsakoff and Organ, 1986).

Insert Table 3 about here

4.3 Estimation method

We estimate linear regression models with the relative importance of secrecy as the dependent variable. The focal independent variables are the legal requirements to disclose information as well as its interaction effects with the technological cluster, investment in fixed assets and past innovation success. Since some of the firms in our sample participated in more than one survey wave, we include a random intercept at the firm level to account for unobserved firm heterogeneity that is not captured by our control variables. In addition, we estimate clustered standard errors at the firm level to account for the autocorrelation between the error terms of the corresponding observations of a firm.

We estimate four model specifications: Model 1 represents a baseline model without interaction effects. In Model 2, we add the interaction between the mandatory information disclosure and the technological cluster. In Model 3, we add the interaction with investment in fixed assets, and Model 4 includes the interaction with past product innovation performance. Hypothesis 1 is tested by the coefficient for the main effect of the mandatory information disclosure dummy in Model 1. Hypotheses 2-4 are tested by the respective coefficient of the interaction effects in Models 2-4. In Model 5 we include all interaction effects simultaneously to show the robustness of our effects

5 Results

5.1 Main results

Table 4 shows the results for all of the model specifications. In line with hypothesis 1, the effect of the legal requirements to disclose information on the relative importance of secrecy is positive and significant (b=.21, se=12, p=.09). Thus, we conclude that the results support hypothesis 1, where we predict that secrecy becomes more important for companies that need to publicly disclose information to shareholders. The effect is sizable given that the average value for the relative importance of secrecy is 0.51. In other words, the relative importance of secrecy is roughly 40 percent higher for firms with mandatory information disclosure requirements. While this relative measure cannot simply be translated into economic impact, it is likely to interfere with important strategic decisions such as “make or buy” (Cassiman and Veugelers, 2006) or strategic alliance decisions (Katila et al., 2008), which have been found to be directly influenced by firm secrecy.

Model 2 shows a significant positive interaction effect of the legal requirements to disclose information variable with location in technological clusters (b=3.20, se=1.23, p<.01). This result supports hypothesis 2, where we postulate that companies that are required to disclose their information publicly attribute more importance to secrecy if they are located within a technological cluster (see Figure 1). Interestingly, the direct effect of the technological cluster location on the relative importance of secrecy is

negative (b=-2.45, se=1.08, p<.05; Table 4). The reason for this may be that companies that are located within geographical clusters need to signal willingness to share information and openness to potential collaborators, making secrecy less important compared to other knowledge protection instruments.

Insert Table 4 about here

Model 3 includes the interaction effect with a firm's investment in fixed assets. The interaction effect is, as expected, positive and significant (b=.36, se=.12, p<.01), thus providing support to hypothesis 3. This shows that for firms that have a legal requirement to disclose information and high investment levels in fixed assets, secrecy becomes more important than for their counterparts with lower levels of investments in fixed assets (see also Figure 2). Interestingly, the direct effect of investment in fixed asset on secrecy is negative (b=-.31, se=.12, p<.001). We can only speculate that these fixed assets can provide complementary assets for the average firm, which would require comparatively less secrecy for appropriating the returns from an innovation. Finally, Model 4 includes the interaction with the past product innovation performance. The interaction is not significant, so we do not find support for hypothesis 4. Model 5 includes all three interaction effects simultaneously. All interactions remain stable in terms of size and significance.

The significant effects of the control variables are in line with the expectations, and they remain stable across the different model specifications. We find significant effects for the variables measuring R&D intensity and process innovation. In addition, firms operating in discrete manufacturing technology, medium high-tech, high-tech industries and technological services assign a higher relative importance to secrecy as a knowledge protection instrument. Lastly, we see temporal effects for the year 2007.

Insert Figures 1 and 2 about here

5.2 Consistency and sensitivity checks

To test the robustness of our results, we apply multiple consistency tests. All robustness estimation results are available upon request from the authors if not directly referenced below. First, we use a different operationalization of the industry classification, and rely on industry dummies based on two-digit NACE codes, instead of the OECD dummies used in the main model. All effects remain robust. Second, we test whether the rate of IPR objections in an industry affects our results and show that, while secrecy becomes more important for companies operating in industries with a high number of patent objections, it does not affect any of our hypothesized results.

Third, we test the robustness of our results toward the different depreciation rates of the patent stock. We run models with patent stock based on depreciation rates between 1 and 20 percent but do not see any effect. Fourth, to show the rationale behind our hypotheses, we test whether the same mechanism we delineate for the importance of secrecy also applies to other knowledge protection instruments, which may be similar in nature, such as complex product design or lead time. We run the same model specifications as in Table 4, but with the relative importance of complex product design and lead time, instead of secrecy. While we find a positive direct effect of mandatory disclosure requirements on the importance of complex design, no effect emerges for lead time, and none of the interaction effects are significant. This finding indicates that our theoretical mechanisms cannot be simply extended to all other knowledge protection instruments. Fifth, we check the robustness of the results towards an alternative operationalization of firm size. We use dummy variables for size classes in the main estimation models because the variable for investments into fixed assets is significantly correlated with a continuous measure of firm size. Using size dummies may limit the models' ability to capture unobserved factors that are correlated with size. Hence, we run additional models with the continuous measure of firm size replacing size dummies in order to test if the hypothesized interaction effect with investments in fixed

assets remains stable. The results are consistent with the findings reported in Table 4 and give us confidence that the results support our theoretical reasoning. Lastly, we test a model specification with a different operationalization of our dependent variable. Specifically, we measure the rank of the importance of secrecy compared to the importance of all other knowledge protection instruments (patents, licenses, complexity of product design, lead time advantages, and copyrights). We rank all instruments based on their stated importance and use the rank of secrecy for each firm as our dependent variable. We use the same independent variable specifications as in Models 1-5 of Table 4, and estimate ordered probit models. The results in Table 5 show that all our focal effects have the same direction and significance as in our main models. Overall, these results underline the robustness and consistency of our estimated effects in the main models.

Insert Table 5 about here

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6 Discussion and Conclusions

6.1 General discussion

In this study, we predict the importance of secrecy for protecting a firm's knowledge based on its visibility to potential imitators. We show that legal requirements to disclose information to the public make secrecy measures for knowledge protection increasingly crucial. Moreover, we find evidence that knowledge protection through secrecy is even more important for firms with legal requirements to disclose information when they have higher fixed assets and are located in technological clusters.

Our findings have important implications for two primary streams of research. First, we go beyond existing literature on knowledge protection and appropriability, which has described the importance of secrecy as based largely on knowledge characteristics, industry factors and cost considerations (James et al., 2013; Bos et al., 2015). Instead, we provide a theoretical model that links the

importance of secrecy to the visibility of firms, thereby emphasizing that its importance is (a) firm-specific and (b) can change with increasing visibility. Secrecy rests on the prevention of information flows, which makes mechanisms from information economics and signaling theory particularly relevant. Future studies may build on our approach and theorize on dynamic, firm-specific vulnerabilities of firms from imitation, thus affecting other knowledge protection instruments such as lead time.

Second, we extend existing research treating the importance attributed to secrecy by a firm as mainly dependent on its industry (Katila et al., 2008). Our findings indicate that more comprehensive approaches to modeling the relationship between knowledge protection and firm performance should model the importance of secrecy endogenously based on firm-specific vulnerabilities originating from signals to imitators. Such models could eradicate potential sources of bias.

Finally, our findings have immediate consequences for the technology management in firms. Our findings indicate that managers should shift attention to secrecy measures such as restricted access to laboratories or databases when the focal firm has to release information publicly and thereby becomes visible to competitors. Investments in such secrecy measures are most pressing when the focal firm is located in a technological cluster and makes investments into fixed assets.

6.2 Future Research

Our study provides new insights into the relationship between firm visibility and knowledge protection strategies at the firm level. First, we focus our attention on one knowledge protection instrument, secrecy, since its effectiveness depends on the creation of information asymmetry between firm insiders and outsiders. However, firms could dynamically adjust their knowledge protection strategies. The particular circumstances under which firms make these changes deserve more attention. In addition, we focus on mandatory information disclosures, which are regulated legally. Companies may decide to provide additional information on a voluntary basis for different strategic reasons. Future studies could investigate whether these voluntary information disclosures affect knowledge protection beyond what we show in

this study for mandatory information disclosure. While our study allows us to distinguish information disclosure requirements for a representative sample of firms, we cannot distinguish the level and quality of information that these firms eventually disclose.

Second, our theoretical reasoning rests on a model of information asymmetry between innovative firms and imitators. These mechanisms may apply to varying degrees to different knowledge protection instruments, e.g., lead time or complex design. Future studies may be able to develop dedicated theoretical models for these knowledge protection instruments. Third, due to the specific structure of our data, we are unable to make causal statements on the relationships that we investigate. Future studies could use field experimental data, or longer panel data with more observations per firm to better model these structural relationships. Fourth, we describe how the importance of secrecy is affected by firms' legal requirements to disclose information. Future studies can extend our model both theoretically as well as empirically and link these changes to innovation performance. Fifth, our data does not allow for a differentiation between the different types of fixed asset investment made by firms. A future study differentiating between R&D and non-R&D fixed assets investment would complement our findings.

A complementary study could focus on how differences in the visibility of innovation related knowledge affect the importance attributed by firms to secrecy. It would be interesting to better distinguish firms that do not attribute importance to secrecy because their knowledge would become inevitably visible from firms that attribute less value to secrecy for strategic reasons. Also, potential imitators differ in their abilities to read signals and to imitate (Zhao, 2006). A dyadic perspective would consider this factor, but the data requirements would be high. Finally, we believe future studies could use more extensive data to better understand and model the two-stage decision process according to which a firm first decides whether to undertake deliberate knowledge protection in a first step and then decides to use secrecy in a second step.

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TABLES

Table 1: Operationalization of variables

Variable	Description
Secrecy	Relative importance of secrecy compared to other knowledge protection instruments
Mandatory information disclosure	Firm has legal requirements to disclose information (1=”yes”/0=”no”)
Share of scientists/engineers to industry and region	Share of engineers and scientists working in a company to total number working in industry and region (%)
Investment in fixed assets	Total investment expenditures for fixed assets
Small firm size	Firms with up to 50 employees (1=”yes”/0=”no”)
Medium firm size	Firm with 50 to 250 employees (1=”yes”/0=”no”)
Large firm size	Firms with more than 250 employees (1=”yes”/0=”no”, baseline)
Past innovation performance	Share of sales with firm novelties to total sales (%)
R&D intensity	Share of R&D expenditures to total sales (%)
Non-R&D innovation expenditures	Total innovation expenditures (including expenditures for equipment, market introduction, licenses, etc.) excluding R&D as a share of total sales (%)
Patent stock	Number of patent applications
Export intensity	Share of exports to total sales (%)
Process innovation	1=”yes”/0=”no process innovation”
Company age	Number of years since founding
Foreign MNC	Firm is part of a foreign multinational group (1=”yes”/0=”no”)
Domestic MNC	Firm is part of a domestic multinational group (1=”yes”/0=”no”)
HHI	Herfindahl concentration index calculated using employee data of firms in an industry (two-digit level)
Share of job switchers to industry and region	Share of employees switching employers of total number employees working in an industry and region (%)
Discrete manufacturing tech.	Dummy variable following industry classification of Cohen et al. (2000)
Medium high-tech manufacturing	1=”yes”/0=”no”
High-tech manufacturing	1=”yes”/0=”no”
Distributive services	1=”yes”/0=”no”
Knowledge-intensive services	1=”yes”/0=”no”
Technological services	1=”yes”/0=”no”
Observation year 2007	1=”yes”/0=”no”
Observation year 2009	1=”yes”/0=”no”
Observation year 2011	1=”yes”/0=”no” (reference year)
Low-tech manufacturing	1=”yes”/0=”no” (reference industry)

*: these variables are transformed as natural logarithms in the model

Table 2: Descriptive statistics

Variable	Obs	Mean	SD	Min	Max
Secrecy	812	0.51	1.03	-2.00	3.00
Mandatory information disclosure	812	0.92	0.27	0.00	1.00
Share of scientists/engineers to industry and region	812	0.03	0.06	0.00	0.81
Investment in fixed assets	812	0.59	0.90	0.00	6.91
Company age	812	2.82	0.94	-4.61	4.61
Small companies	812	0.42	0.49	0.00	1.00
Medium companies	812	0.37	0.48	0.00	1.00
Past innovation performance	812	0.23	0.23	0.00	1.00
Foreign MNC	812	0.06	0.24	0.00	1.00
Domestic MNC	812	0.11	0.32	0.00	1.00
R&D intensity	812	0.05	0.12	0.00	1.00
Non-R&D innovation expenditures (ratio)	812	0.04	0.08	0.00	0.80
Patent stock	812	-3.03	2.56	-4.61	6.24
Export intensity	812	0.22	0.26	0.00	1.00
Process innovation	812	0.58	0.49	0.00	1.00
HHI	812	5.84	17.93	0.11	379.14
Share of job switchers in industry and region	812	0.12	0.09	0.02	0.87
Discrete manufacturing tech.	812	0.34	0.47	0.00	1.00
Medium high-tech manufacturing	812	0.21	0.41	0.00	1.00
High-tech manufacturing	812	0.11	0.32	0.00	1.00
Distributive services	812	0.10	0.29	0.00	1.00
Knowledge-intensive services	812	0.05	0.21	0.00	1.00
Technological services	812	0.17	0.37	0.00	1.00
Observation year 2007	812	0.40	0.49	0.00	1.00
Observation year 2009	812	0.35	0.48	0.00	1.00
Observation year 2001	812	0.26	0.44	0.00	1.00
Low-tech manufacturing	812	0.36	0.48	0.00	1.00
Large companies	812	0.22	0.41	0.00	1.00

Table 3: Correlation table

	Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Secrecy	1																							
2	MDI	0.08	1.00																						
3	Share of scientists/engineers	0.00	-0.03	1.00																					
4	Investment in fixed assets	0.01	0.05	0.01	1.00																				
5	Company age	-0.07	-0.05	0.03	0.12	1.00																			
6	Small companies	-0.01	-0.13	-0.06	-0.45	-0.15	1.00																		
7	Medium companies	0.00	0.09	0.05	-0.08	0.03	-0.64	1.00																	
8	Past innovation performance	0.13	0.03	-0.07	-0.08	-0.14	0.05	0.06	1.00																
9	Foreign MNC	-0.02	0.08	0.06	0.12	0.00	-0.20	0.09	-0.03	1.00															
10	Domestic MNC	0.02	0.06	-0.02	0.20	0.12	-0.28	0.05	-0.07	-0.09	1.00														
11	R&D intensity	0.08	-0.05	-0.03	-0.10	-0.07	0.16	-0.07	0.26	-0.04	-0.09	1.00													
12	Non-R&D innovation	0.05	-0.01	-0.03	-0.07	-0.12	0.16	-0.06	0.21	0.01	-0.09	0.17	1.00												
13	Patent stock	0.03	0.08	-0.03	0.42	0.12	-0.31	-0.03	0.07	0.14	0.31	0.18	-0.01	1.00											
14	Export intensity	0.08	0.15	-0.05	0.22	0.11	-0.26	0.05	0.02	0.17	0.27	-0.02	-0.04	0.49	1.00										
15	Process innovation	0.06	-0.03	0.00	0.15	0.02	-0.11	0.03	-0.03	0.03	0.05	-0.03	0.01	0.12	0.03	1.00									
16	HHI	-0.03	0.02	0.09	0.08	0.04	-0.06	-0.04	-0.03	0.09	0.06	-0.03	-0.04	0.01	0.00	0.00	1.00								
17	Share of job switchers	-0.07	-0.09	0.10	-0.09	-0.05	0.13	-0.06	-0.07	-0.04	-0.12	-0.05	0.00	-0.22	-0.28	-0.01	0.01	1.00							
18	Discrete manufacturing tech.	0.05	0.09	0.04	0.11	0.03	-0.06	0.00	-0.14	0.11	0.07	-0.14	-0.10	0.00	0.05	0.05	0.09	-0.22	1.00						
19	Medium high-tech	0.09	0.09	-0.10	0.15	0.10	-0.18	0.00	0.02	0.03	0.21	-0.06	-0.03	0.28	0.36	0.00	0.02	-0.30	-0.11	1.00					
20	High-tech manufacturing	0.02	0.01	-0.07	-0.09	0.02	0.04	0.06	0.10	0.00	-0.07	0.10	-0.03	0.08	0.11	-0.03	0.01	-0.13	-0.13	-0.19	1.00				
21	Distributive services	-0.13	-0.07	0.07	-0.04	0.04	0.01	0.05	-0.09	-0.03	-0.05	-0.11	0.02	-0.18	-0.20	-0.03	0.03	0.19	-0.24	-0.17	-0.12	1.00			
22	Knowledge-int. services	-0.02	-0.08	0.10	-0.09	0.01	0.03	-0.04	-0.09	-0.03	-0.04	-0.08	-0.07	-0.13	-0.18	0.05	0.03	0.38	-0.16	-0.12	-0.08	-0.07	1.00		
23	Technological services	0.04	-0.08	-0.04	-0.17	-0.18	0.25	-0.11	0.14	-0.07	-0.13	0.33	0.23	-0.11	-0.20	-0.03	-0.07	0.34	-0.32	-0.23	-0.16	-0.14	-0.10	1.00	
24	Observation year 2007	0.18	0.04	0.00	-0.01	-0.04	-0.01	0.00	0.12	0.08	0.14	0.02	0.07	0.04	0.09	-0.02	-0.01	-0.17	0.01	0.03	0.02	-0.04	-0.05	-0.02	1.00
25	Observation year 2009	-0.15	-0.04	0.04	-0.07	0.11	0.04	0.00	-0.15	0.06	0.05	0.06	-0.08	0.08	0.06	-0.01	0.05	0.01	0.02	0.03	0.05	-0.05	-0.01	-0.02	-0.59

Table 4: Estimation results

	Model 1		Model 2		Model 3		Model 4		Model 5	
	b (se)		b (se)		b (se)		b (se)		b (se)	
Mandatory information disclosure (MDI)	0.21	*	0.09		0.04		0.22		-0.11	
	(0.12)		(0.14)		(0.13)		(0.16)		(0.17)	
MDI*Technological cluster			3.20	***					3.70	***
			(1.23)						(1.27)	
MDI*Fixed assets					0.36	***			0.38	***
					(0.12)				(0.12)	
MDI*Past innovation performance							-0.03		0.04	
							(0.62)		(0.59)	
Technological cluster location	0.47		-2.45	**	0.44		0.47		-2.95	***
	(0.59)		(1.08)		(0.60)		(0.59)		(1.13)	
Investment in fixed assets	0.03		0.03		-0.31	***	0.03		-0.33	***
	(0.06)		(0.06)		(0.12)		(0.06)		(0.12)	
Past innovation performance	0.38	**	0.38	**	0.39	**	0.41		0.35	
	(0.17)		(0.17)		(0.17)		(0.62)		(0.58)	
Company age	-0.04		-0.04		-0.04		-0.04		-0.04	
	(0.04)		(0.04)		(0.04)		(0.04)		(0.04)	
Small firm size	-0.01		0.00		-0.04		-0.01		-0.02	
	(0.13)		(0.14)		(0.14)		(0.13)		(0.14)	
Medium firm size	0.00		0.01		-0.01		0.00		0.00	
	(0.12)		(0.12)		(0.12)		(0.12)		(0.12)	
Foreign MNC	-0.22		-0.22		-0.23		-0.22		-0.23	
	(0.15)		(0.15)		(0.15)		(0.15)		(0.15)	
Domestic MNC	-0.05		-0.05		-0.06		-0.05		-0.06	
	(0.13)		(0.13)		(0.13)		(0.13)		(0.13)	
R&D intensity	0.56	*	0.54	*	0.58	*	0.55	*	0.56	*
	(0.30)		(0.30)		(0.30)		(0.31)		(0.31)	
Non-R&D innovation expenditures	0.12		0.10		0.23		0.12		0.20	
	(0.37)		(0.37)		(0.37)		(0.37)		(0.38)	
Patent stock	-0.02		-0.02		-0.02		-0.02		-0.02	
	(0.02)		(0.02)		(0.02)		(0.02)		(0.02)	
Share exports to sales	0.21		0.21		0.22		0.21		0.22	
	(0.17)		(0.17)		(0.17)		(0.17)		(0.17)	
Process innovation	0.13	*	0.13	*	0.11		0.13	*	0.12	
	(0.07)		(0.07)		(0.07)		(0.07)		(0.07)	
HHI	0.00		0.00		0.00		0.00		0.00	
	(0.00)		(0.00)		(0.00)		(0.00)		(0.00)	
Share of job switchers in industry and region	0.00		-0.09		-0.02		0.00		-0.12	
	(0.51)		(0.51)		(0.51)		(0.51)		(0.51)	
Discrete manufacturing technology	0.27	**	0.27	**	0.27	**	0.27	**	0.27	**
	(0.11)		(0.11)		(0.11)		(0.11)		(0.11)	

	Model 1		Model 2		Model 3		Model 4		Model 5	
	b (se)		b (se)		b (se)		b (se)		b (se)	
Medium high-tech manufacturing	0.34	***	0.35	***	0.34	***	0.34	***	0.35	***
	(0.12)		(0.12)		(0.11)		(0.12)		(0.11)	
High-tech manufacturing	0.20		0.21		0.21		0.20		0.21	
	(0.14)		(0.14)		(0.14)		(0.14)		(0.14)	
Distributive services	-0.09		-0.08		-0.09		-0.09		-0.08	
	(0.15)		(0.15)		(0.15)		(0.15)		(0.15)	
Knowledge-intens. services	0.23		0.30		0.23		0.23		0.31	
	(0.21)		(0.21)		(0.21)		(0.21)		(0.21)	
Technological services	0.26	*	0.27	*	0.27	*	0.26	*	0.28	*
	(0.16)		(0.16)		(0.16)		(0.16)		(0.16)	
Observation year 2007	0.27	***	0.27	***	0.26	***	0.27	***	0.27	***
	(0.10)		(0.10)		(0.10)		(0.10)		(0.10)	
Observation year 2009	-0.13		-0.13		-0.13		-0.13		-0.13	
	(0.10)		(0.10)		(0.10)		(0.10)		(0.10)	
Constant	-0.16		-0.05		0.00		-0.16		0.14	
	(0.27)		(0.27)		(0.26)		(0.29)		(0.29)	
Overall R^2	0.09		0.09		0.10		0.09		0.10	
Wald Chi^2	105.83		114.91		111.82		106.07		122.68	
p-value	0.00		0.00		0.00		0.00		0.00	

***: p<.01, **: p<.05, *: p<.10

Table 5: Results of ordered probit model with alternative measure of the secrecy importance

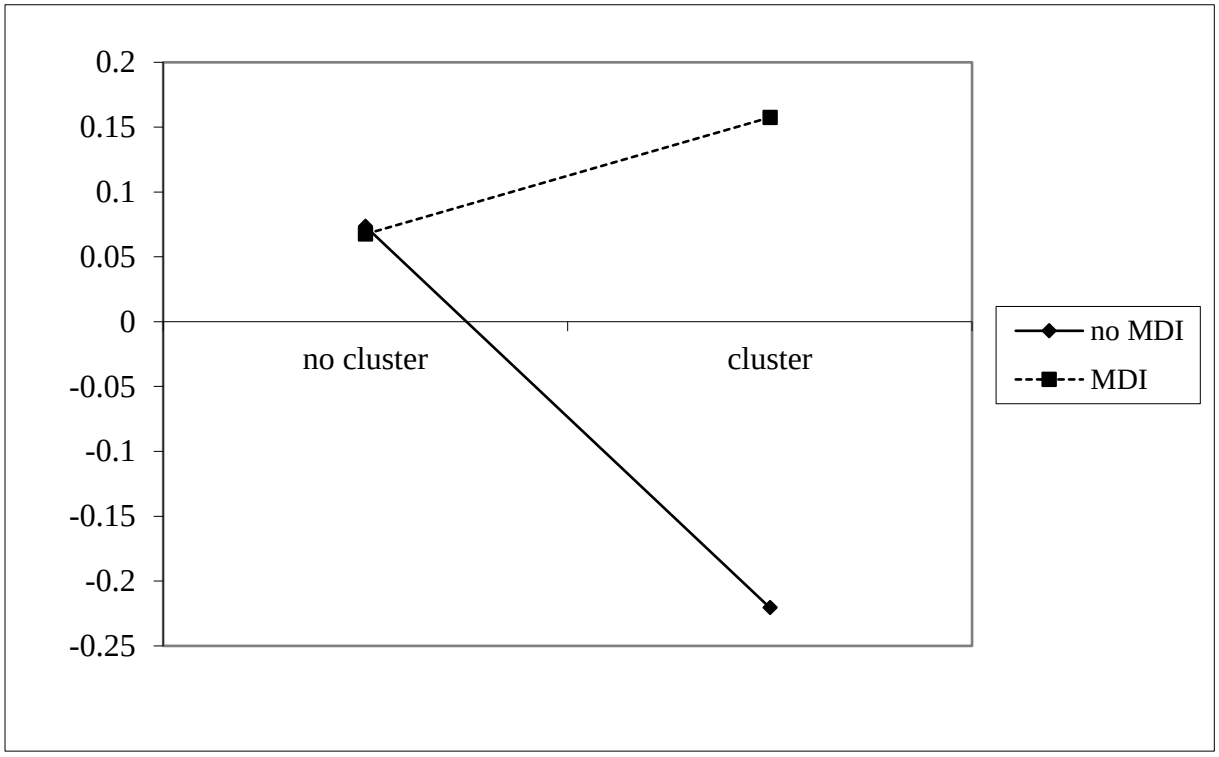
	Model 1		Model 2		Model 3		Model 4		Model 5	
	b (se)		b (se)		b (se)		b (se)		b (se)	
Mandatory information disclosure (MDI)	0.36	*	0.05		0.20		0.46		-0.11	
	(0.22)		(0.26)		(0.24)		(0.31)		(0.37)	
MDI*Technological cluster			11.08	*					11.25	**
			(5.78)						(5.56)	
MDI*Fixed assets					0.38	*			0.43	**
					(0.19)				(0.19)	
MDI*Past innovation performance							-0.42		-0.17	
							(0.95)		(0.95)	
Technological cluster location	0.35		-10.39	*	0.32		0.36		-10.56	*
	(0.82)		(5.71)		(0.82)		(0.82)		(5.48)	
Investment in fixed assets	0.08		0.08		-0.28		0.08		-0.33	*
	(0.09)		(0.09)		(0.19)		(0.09)		(0.19)	
Past innovation performance	0.42	*	0.41	*	0.43	*	0.81		0.57	
	(0.23)		(0.23)		(0.23)		(0.94)		(0.95)	
Company age	-0.04		-0.04		-0.03		-0.04		-0.03	
	(0.06)		(0.06)		(0.06)		(0.06)		(0.06)	
Small firm (<50)	0.08		0.09		0.06		0.08		0.07	
	(0.18)		(0.19)		(0.18)		(0.18)		(0.19)	
Medium sized firm (>=50, <250)	0.10		0.09		0.09		0.09		0.08	
	(0.16)		(0.16)		(0.16)		(0.16)		(0.16)	
Foreign MNC	-0.37	*	-0.37	*	-0.38	*	-0.37	*	-0.38	*
	(0.22)		(0.22)		(0.22)		(0.22)		(0.22)	
Domestic MNC	-0.06		-0.06		-0.06		-0.06		-0.06	
	(0.15)		(0.15)		(0.15)		(0.15)		(0.15)	
R&D intensity	0.61		0.58		0.62	*	0.57		0.58	
	(0.37)		(0.37)		(0.37)		(0.38)		(0.38)	
Non-R&D innovation expenditures	0.00		-0.03		0.08		0.02		0.07	
	(0.54)		(0.54)		(0.54)		(0.54)		(0.54)	
Patent stock	0.01		0.01		0.01		0.01		0.01	
	(0.02)		(0.02)		(0.02)		(0.02)		(0.02)	
Share exports to sales	0.44	**	0.44	**	0.44	**	0.44	**	0.44	**
	(0.22)		(0.22)		(0.22)		(0.22)		(0.22)	
Process innovation	0.19	*	0.20	**	0.18	*	0.19	*	0.18	*
	(0.10)		(0.10)		(0.10)		(0.10)		(0.10)	
HHI	-0.01		-0.01		-0.01		-0.01		-0.01	*
	(0.00)		(0.00)		(0.00)		(0.00)		(0.00)	
Share of job switchers in industry and region	0.56		0.43		0.54		0.55		0.40	
	(0.82)		(0.83)		(0.82)		(0.82)		(0.83)	
Discrete manufacturing technology	0.26	*	0.27	*	0.26	*	0.26	*	0.27	*
	(0.14)		(0.14)		(0.14)		(0.14)		(0.14)	
Medium high-tech manufacturing	0.32	**	0.32	**	0.32	**	0.32	**	0.32	**

	Model 1		Model 2		Model 3		Model 4		Model 5	
	b (se)		b (se)		b (se)		b (se)		b (se)	
	(0.14)		(0.14)		(0.14)		(0.14)		(0.14)	
High-tech manufacturing	0.34	*	0.34	*	0.34	*	0.34	*	0.35	*
	(0.18)		(0.18)		(0.18)		(0.18)		(0.18)	
Distributive services	-0.73	***	-0.72	***	-0.73	***	-0.73	***	-0.72	***
	(0.27)		(0.27)		(0.27)		(0.27)		(0.27)	
Knowledge-intens. services	-0.17		-0.07		-0.17		-0.16		-0.06	
	(0.35)		(0.36)		(0.35)		(0.35)		(0.36)	
Technological services	0.20		0.21		0.21		0.21		0.22	
	(0.21)		(0.21)		(0.21)		(0.21)		(0.21)	
Observation year 2007	0.51	***	0.52	***	0.51	***	0.52	***	0.51	***
	(0.15)		(0.15)		(0.15)		(0.15)		(0.15)	
Observation year 2009	0.37	**	0.36	**	0.37	**	0.37	**	0.36	**
	(0.14)		(0.14)		(0.14)		(0.14)		(0.14)	
Constant										
	(0.24)		(0.23)		(0.24)		(0.24)		(0.23)	
R^2	812.00		812.00		812.00		812.00		812.00	
N	61.68		61.82		63.66		62.04		65.24	

***: p<.01, **: p<.05, *: p<.10

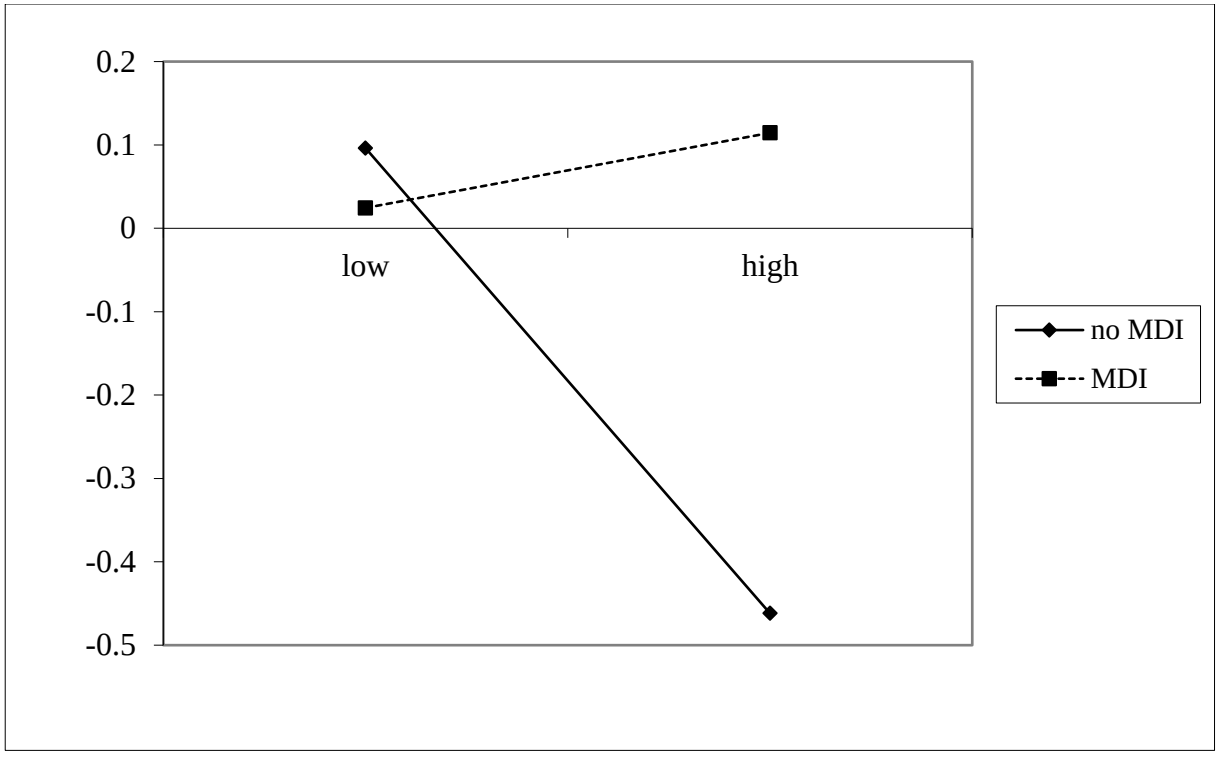
FIGURES

Figure 1: Interaction effect between the variables mandatory information disclosure (MDI) and technological cluster



Note: "no cluster" represents a share of engineers and scientists relative to region and industry which is lower than the sample mean by one standard deviation; "cluster" represents a share of engineers and scientists relative to region and industry which is higher than the sample mean by one standard deviation.

Figure 2: Interaction effect between the variables mandatory information disclosure (MDI) and investment in fixed assets



Note: “low” represents firms with a lower level of investment in fixed assets than the sample mean by one standard deviation; “high” represents firms with a higher level of investment in fixed assets than the sample mean by one standard deviation.

Appendix A: Example quotes for secrecy measures from expert interviews

Position of interviewee	Industry	Description of secrecy measures
Project manager	Manufacturer of chemical products	For our company, protection of internal information plays a central role for product and process innovation and for acquisitions. To protect our knowledge and ensure secrecy, we thus have multiple processes. For example, our company has specific nondisclosure and secrecy agreements that must be signed in order to receive access to selected IT systems or buildings. Also, we have research agreements with third-party collaborators, which include separate secrecy agreements, partly with significant financial penalties. We also offer regular trainings on information protection to our employees, who then must pass a test.
Strategy consultant	IT company	Much like any other technology company, we have numerous policies in place to ensure the protection of the company's intellectual property and confidential information, particularly regarding new product development but also in respect to our business operations in general. Employees are trained regularly regarding adherence to these policies. More general examples include predefined confidentiality levels for certain types of information and required authorization for disseminating information. Product development specific examples are non-disclosure agreements for co-innovations or the testing of prototypes with end-users.
Chief data scientist	IT company with focus on artificial intelligence and predictive analytics	In order to assure that we can protect our relevant intellectual property and data, we put the following processes in motion: - Every employee is contractually obliged to transfer all IP rights of his or her work immediately to the company; - Every employee is sworn in to data privacy; - We do not make the source code of our software publicly accessible; - We do not use printouts, USB sticks or any other removable media for sensible information - We use two-factor authentication as the only means of access to our source code and production data; - Production data are never stored on any mobile devices like PCs or phones, only on the central server; - Source code is only stored on the central server and on encrypted devices that are password-protected; and - External collaborations are accompanied by a mutual NDA agreement that ensures that all exchanged information stays confident. These NDA agreements ensure that all exchanged information, code,

		concepts etc. must stay privileged unless they are already common facts.
Sales director	Leisure services	As a distributive service company we do not develop proprietary products. However, protection of sensitive (e.g., customer) data, as well as process innovations is very relevant for us. For this, we have very strict regulations on how to access and handle sensitive data. Every employee has to sign nondisclosure agreements, and is trained before gaining access to the IT system. Also, external collaborations are always accompanied by a mutual NDA agreement that encompasses all exchanged sensitive information. In some cases, external collaborators have to sign a competition clause, which forbids them from transferring processes specific to our company to other customers.
Director strategy	Advertising agency	For our industry, protection of information is essential. For this, we have very strict regulations. Every employee is sworn to data privacy. Employees are not allowed to have printouts of any customer presentation, or other sensitive information in their working stations. All employees have to sign contracts with specific regulations on data protection and secrecy, partly with financial penalties. Employees in central positions have to sign competition clauses that prohibit them from switching to our direct competitors after they leave the company. In the case of advertising campaigns for innovative products that are not yet introduced into the market, employees have to work in offices without windows, or with covered windows in order to minimize the risk that the product design, e.g., of new cars, is revealed before its market introduction.